THE REFLECTED IMPULSE ON A CURVED WALL PRODUCED BY A SPHERICAL EXPLOSION IN AIR

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ABSTRACT

The paper deals with the impulse on a concave wall resulting from the reflection of the spherical blast wave of an explosion in air. This situation arises when a spherical blast wave hits a non-planar surface, such as the wall of a containment vessel. Two types of surfaces are considered, cylindrical and spherical, in addition to the standard plane wall. The work is based on computations with the PISCES two-dimensional flow code, employing second order numerical schemes. The results for the plane surface are compared with the compiled experimental data in the literature. The study was carried out for a 2 Kg TNT charge at a distance of 1 m from the surface, assuming that the radii of the cylinder or sphere are also 1 meter. It was found that the reflected impulse on a cylindrical surface is ≈18% over the plane wall case. For a spherical wall the reflected impulse (for the first shock reverberation) is about 50% over the plane wall impulse.

INTRODUCTION

In designing structures to withstand the effects of explosions, the relevant blast parameter is usually the impulse contained in the pressure pulse, and not the pressure itself. The reason for this is that most structures have a long response time compared to the blast wave duration.

The blast wave parameters for spherical explosions in air was dealt with in many publications. The results were compiled by Baker [1], and Baker et al. [2]. The data in these references comprise also the reflected impulse on a plane wall. In practical problems, however, there is a need for estimating the reflected impulse on a curved wall, such as in designing cylindrical or spherical containment vessels. The present paper aims to obtain an estimate of the reflected impulse on concave walls. Two types of walls are considered in the present paper: cylindrical and spherical. In both cases the charge is assumed to be located at a distance equal to the radius of curvature of the surface. This means that the charge lies along the axis of symmetry, in the case of the cylindrical surface, and on the center, for the spherical surface. (See Fig.1).

The present study is limited to one value of the shock parameter,

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$$R/W^{1/3} = 2\ ft/Lb^{1/3}\ (\approx 0.8\ m/Kg^{1/3})$$

where R is the distance from the center of the charge and W is the charge weight. Actually, the calculations were carried out with the following values:

$$R = 1\ m$$
$$W = 2\ Kg\ (TNT)$$

Using the similarity rules for explosions in air (at sea level conditions), we may apply the results of the present calculations to other combinations of R and W according to the relation

$$i/W^{1/3} = f(\ R/W^{1/3})$$

$$i = \int (P_w - P_o)dt$$

where i is the impulse per unit area of the reflected wave, Po and Pw are the atmospheric pressure and the reflected wave pressure, respectively, and t is the time. It should be stressed, however, that this relation strictly holds for the situation described above, i.e. that the charge is located at the center of the surface, so that R = Rc, where Rc is the radius of curvature. Otherwise, the similarity rule should be modified to take into account the wall curvature. This modified rule would have the form:

$$i/W^{1/3} = f\ (R/W^{1/3},\ Rc/R)$$

THE COMPUTATIONAL MODEL

The solution to the problem is obtained numerically, using the PISCES 2DELK hydrocode [3]. This code has a second order Eulerian processor with a multi- material capability, so that a different equation of state may be employed to describe the ambient air and the explosion products.

The computational model consists of a quadrilateral grid for the cylindrical surface case, and a wedge-like grid for the spherical surface case. (Fig.1). The axis of symmetry and the surface on which the wave is reflected are defined by a "rigid wall" boundary condition. For the plane surface case, a "continuative flow" boundary condition was employed at the open sides of the grid, to minimize edge effects.

The air is described by an ideal gas equation of state, with a specific heat ratio τ=1.4. The explosive charge is approximated by a sphere of dense gas, with τ=1.3. Although this representation of the detonation products is very crude, especially at the high pressure regime, it produces the correct blast wave impulse. This result was verified by varying the equation of state of the detonation products and examining the resulting impulse. Such studies show that although some details of the flow field depend on the equation of state, the impulse is insensitive to it. A similar approach was employed in treating air blasts induced by high explosives in previous works [4,5].

In accordance with the above description, the initial conditions are uniform pressure and density in the entire mesh, except for a small spherical region which represents the high explosive. The initial conditions in the ambient air are:

$$\rho = 1.25 \text{ Kg/m}^3$$

$$p = 0.1 \text{ MPa}$$

and the initial conditions for the detonation products are:

$$\rho = 1600 \text{ Kg/m}^3$$

$$e = 4.1 \text{ MJ/Kg}$$

where e, the specific internal energy of the explosive, was taken from [6].

THE NUMERICAL SOLUTION

The results of the flow simulation will be described in some detail for the plane surface case. The computational grids are shown in Fig.2. In these grids the cell size varies as a geometrical series in both directions. In this way the flow field details are preserved in the early stages of the blast wave formation, when the flow gradients are very large. The grid shown in Fig.2a has a geometric ratio of 1.032, which produces a very fine grid in the vicinity of the origin, so that the charge occupies about seven mesh cells radially. This grid was used up to t = 0.2 ms, when rezoning to the coarser grid of Fig.2b was carried out. The new grid had a geometric ratio of 1.02, and was used to the end of the calculation without further changes.

Fig.3 shows the flow field at t=0.2 ms. The symmetry of the flow is not perfect, due to numerical effects near the axis of symmetry. This asymmetry increases at later times, but the solution is still acceptable since the main objective of the work is the integrated impulse, and the details of the pressure time history do not affect the impulse significantly.

The flow field at t=0.6 ms is shown in Fig.4. At this time the main shock wave has already hit the wall and a reflected wave was created. At later times, (Figs.5 and 6), the reflected wave moves farther from the wall. At t=1.0 ms the pressure near the wall has dropped to about 0.2 MPa (twice the atmospheric pressure), and at t=1.35 ms the pressure is below atmospheric, and no further positive contribution to the impulse is made beyond this time.

The calculations for the other cases were carried out similarly. In fact, the first phase of the blast wave calculation (to 0.2 ms) described above was used to create a starting state for the other cases using appropriate rezoning.

RESULTS AND DISCUSSION

The impulse per unit area on the wall is defined by:

$$i(t) = \int_0^t [P(t') - P_o]\, dt'$$

The blast wave is characterized by a high peak followed by a quick decay to below atmospheric pressure. The relevant impulse for structural response in most cases is the peak value, which corresponds to positive overpressure.

Fig.7 shows the time history of the impulse for the three cases. The peak pressure is identical for the three types of surfaces, and therefore the curves coincide for early times. At later times, however, the differences in wall curvature affect the local flow, with a corresponding effect on the wall impulse.

For the plane surface, the peak impulse is attained at t≈1.1 ms, about 0.6ms after the shock front arrival. The peak value is 0.80 MPa-ms. This value should be compared with the compiled data of [2], which predict an impulse of 0.87 MPa-ms. The difference (≈8%) is reasonable in view of the scatter in the experimental results.

For the cylindrical surface, the peak impulse is attained somewhat later, at t=1.6 ms. However, about 98% of the peak is obtained at t=1.2 ms. The peak impulse is 0.94 MPa-ms, 17.5% over the plane surface case.

The impulse curve for the spherical case exhibits a different behavior. In this case, due to the spherical symmetry, shock wave reverberations occur between the wall and the origin. The timing is such that the reflected wave from the center hits the wall and contributes further to the impulse, before its "saturation" due to the local flow is completed. In this case it is difficult to define the maximum impulse. For the purpose of comparing with the other cases, one may take the value just before arrival of the reflected wave from the origin. This value is 1.22 MPa-ms, about 53% over the plane surface case, and about 30% over the cylindrical surface case.

CONCLUSIONS

The impulse produced on a curved wall by a spherical explosion in air depends on the local wall curvature. For the special case of explosion at the center of a cylindrical or spherical surface, the following values were obtained using hydrocode calculations,

Plane Surface:	0.80 MPa-ms
Cylindrical Surface:	0.94 MPa-ms.
Spherical Surface:	1.22 MPa-ms.

These values were obtained for a TNT charge of 2 Kg, at a distance of 1 m. They may be extrapolated to other combinations of charge weight and distance according to the well known similarity rule for scaling impulse data, as explained in the introduction.

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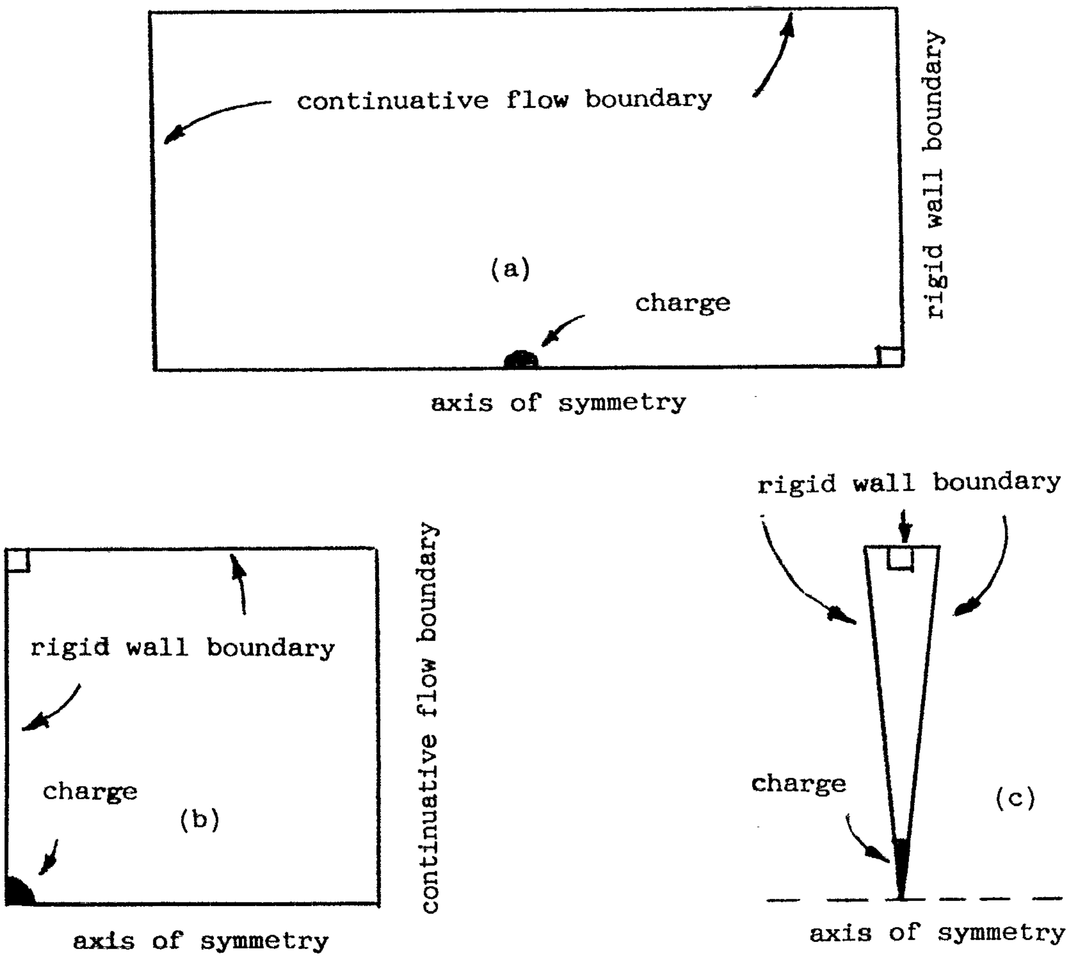

FIGURE 1: COMPUTATIONAL SET-UP FOR THE PROBLEM
(a) Plane Surface
(b) Cylindrical Surface
(c) Spherical Surface

□ location of impulse computation

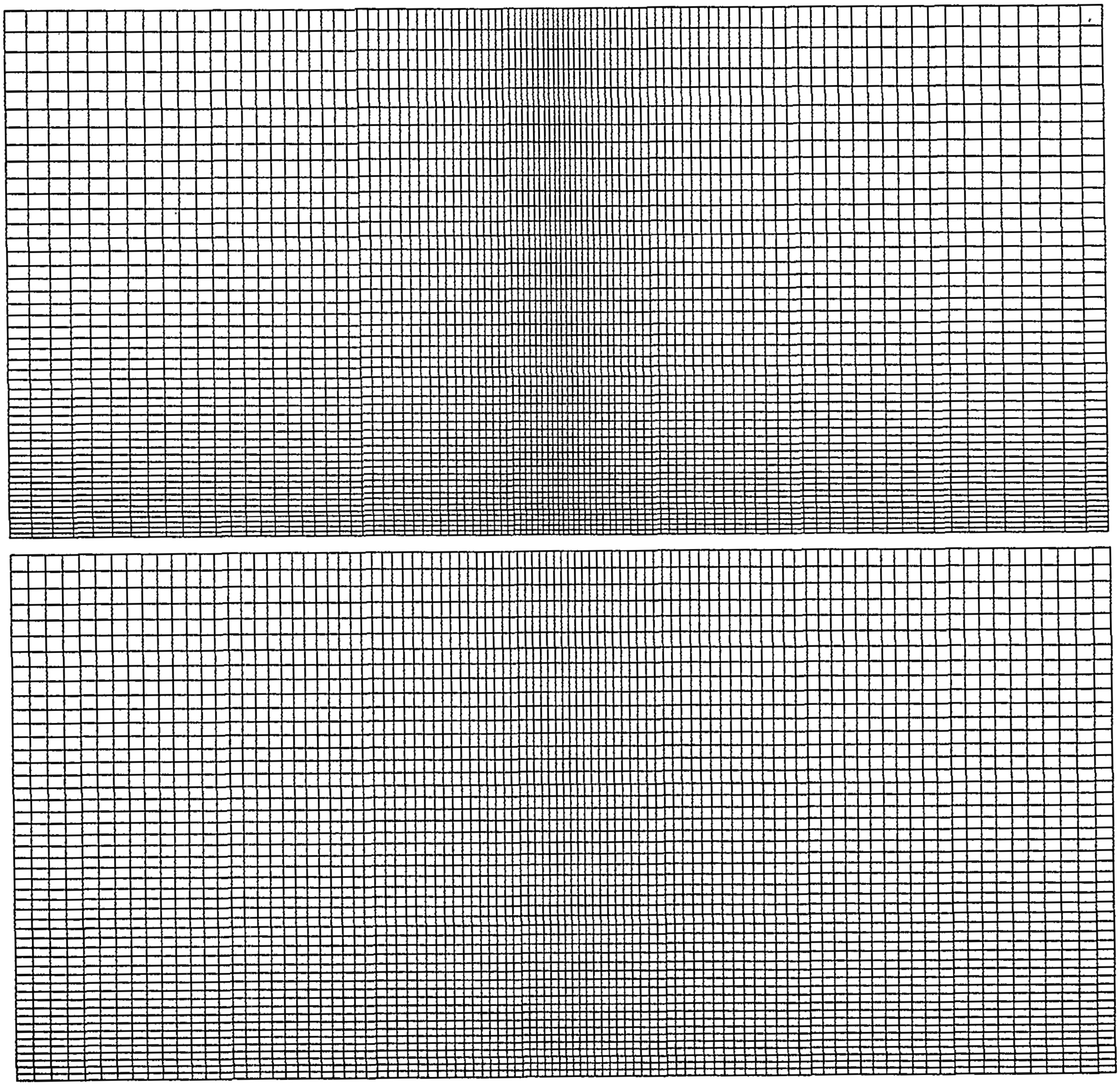

FIGURE 2: THE COMPUTATIONAL GRID FOR THE PLANE SURFACE CASE
Top: The grid for $0 < t < 0.2$ ms. Geometric ratio = 1.032
Botttom: The grid for $t > 0.2$ ms. Geometric ratio = 1.020

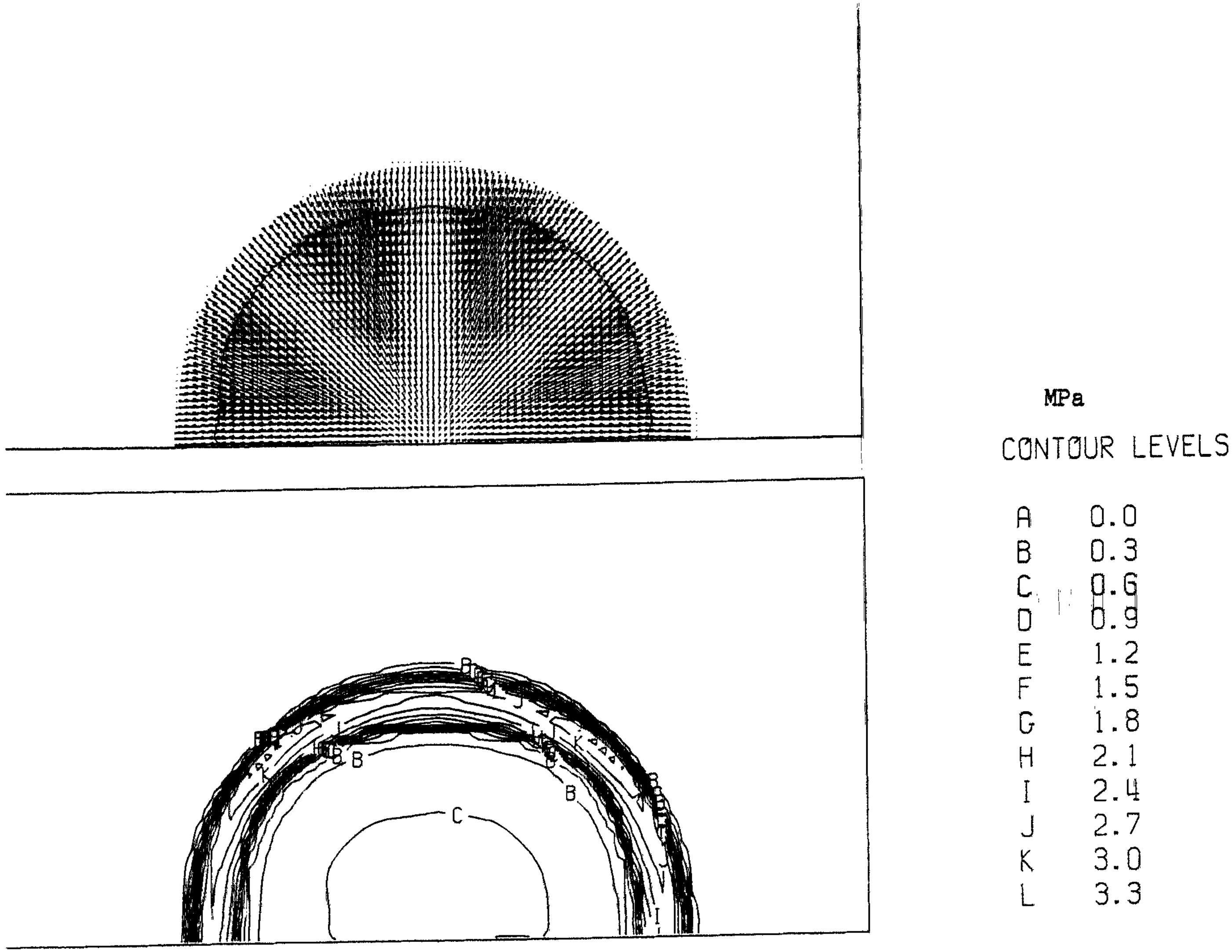

FIGURE 3: VELOCITY VECTOR PLOT AND PRESSURE CONTOURS AT t = 0.2 ms.

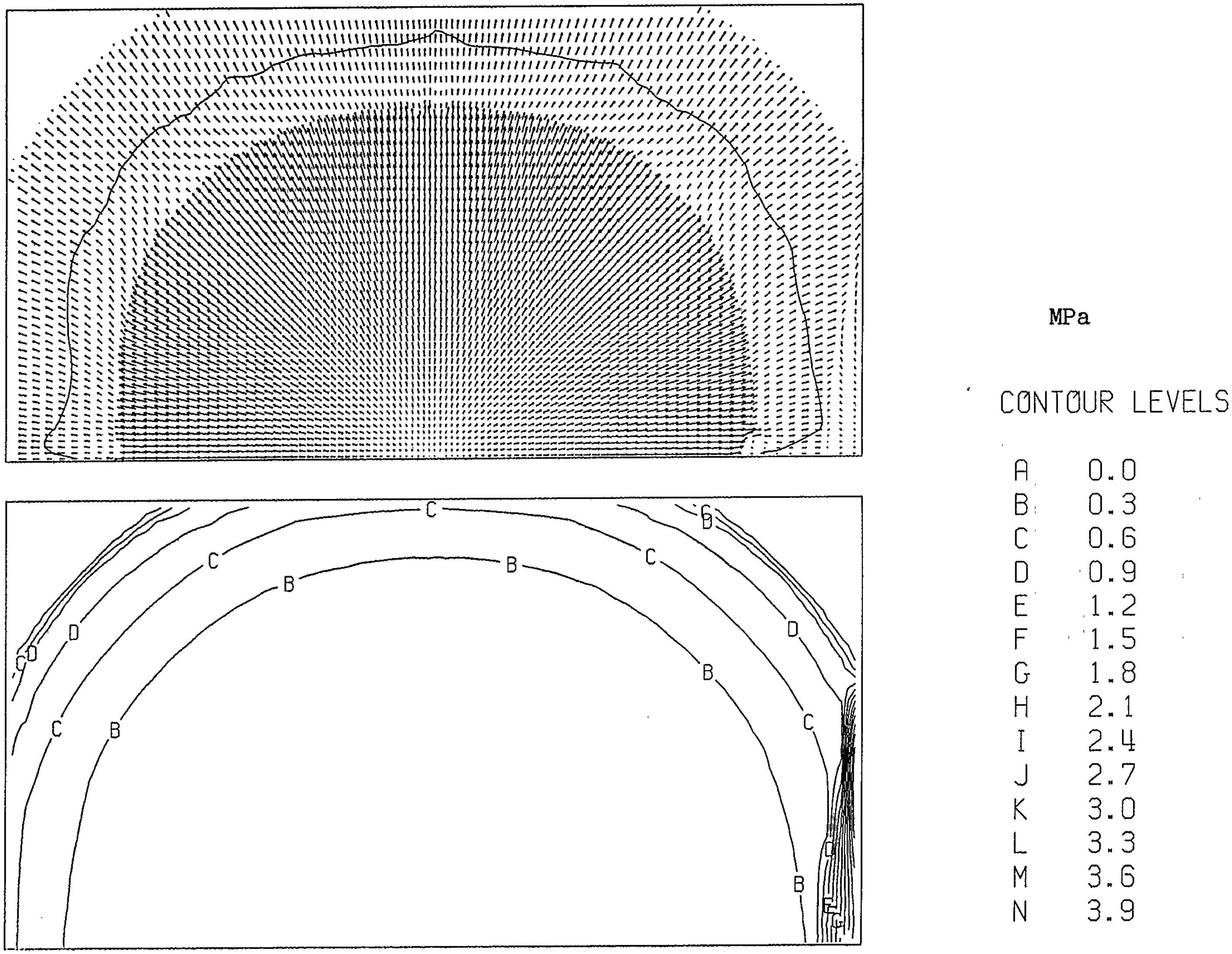

FIGURE 4: VELOCITY VECTOR PLOT AND PRESSURE CONTOURS AT t = 0.6 ms.

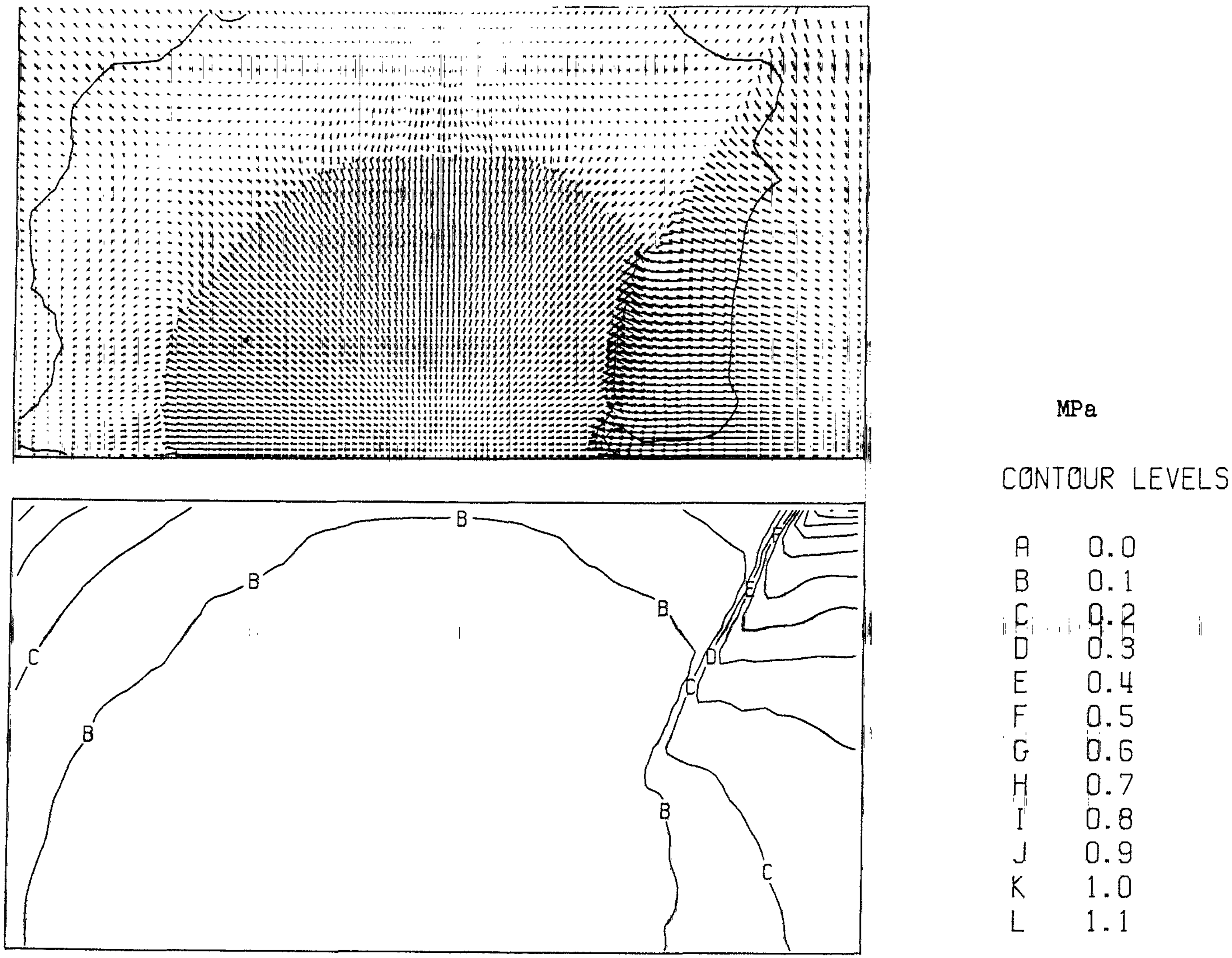

FIGURE 5: VELOCITY VECTOR PLOT AND PRESSURE CONTOURS AT t = 1.0 ms.

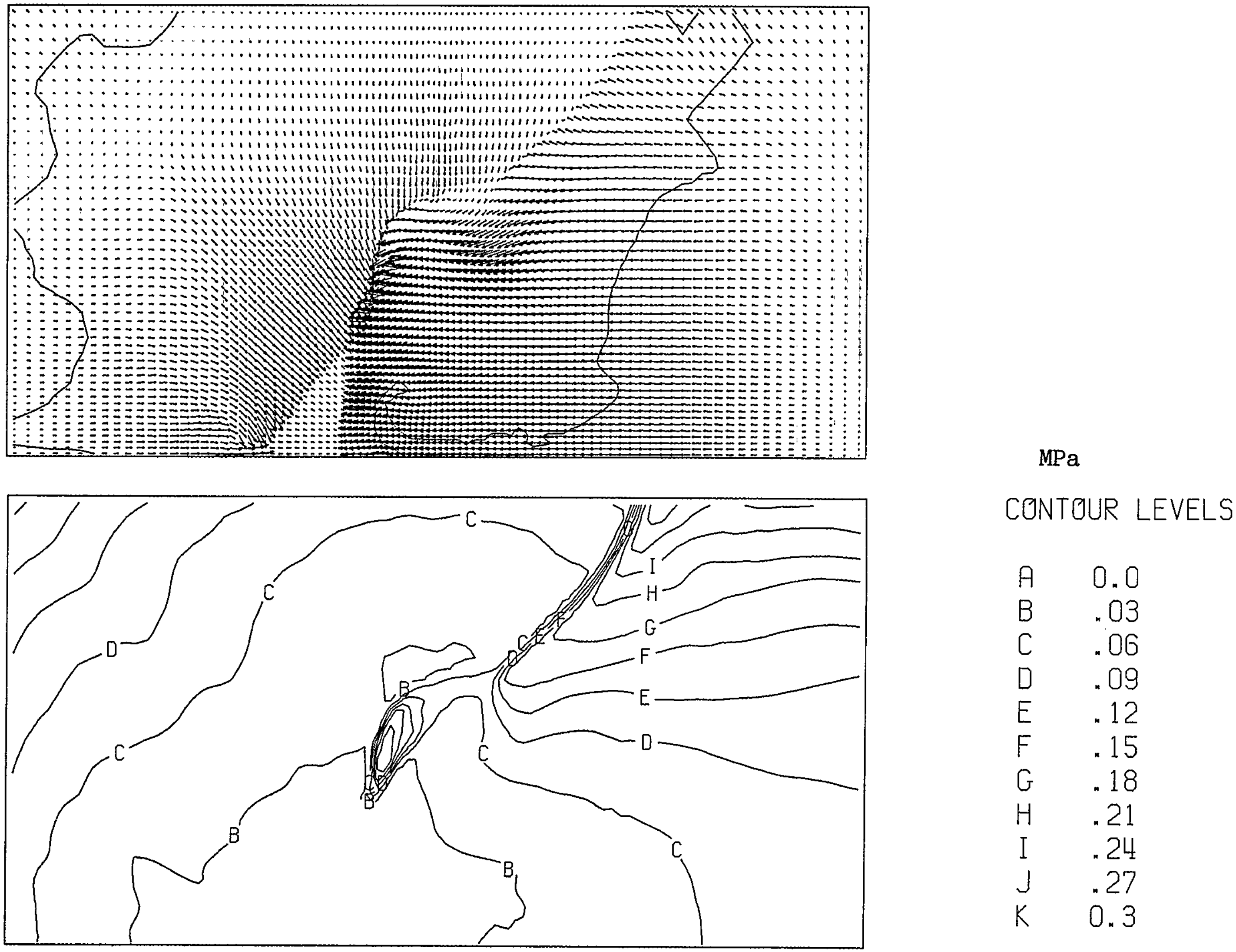

FIGURE 6: VELOCITY VECTOR PLOT AND PRESSURE CONTOURS AT t = 1.35 ms.

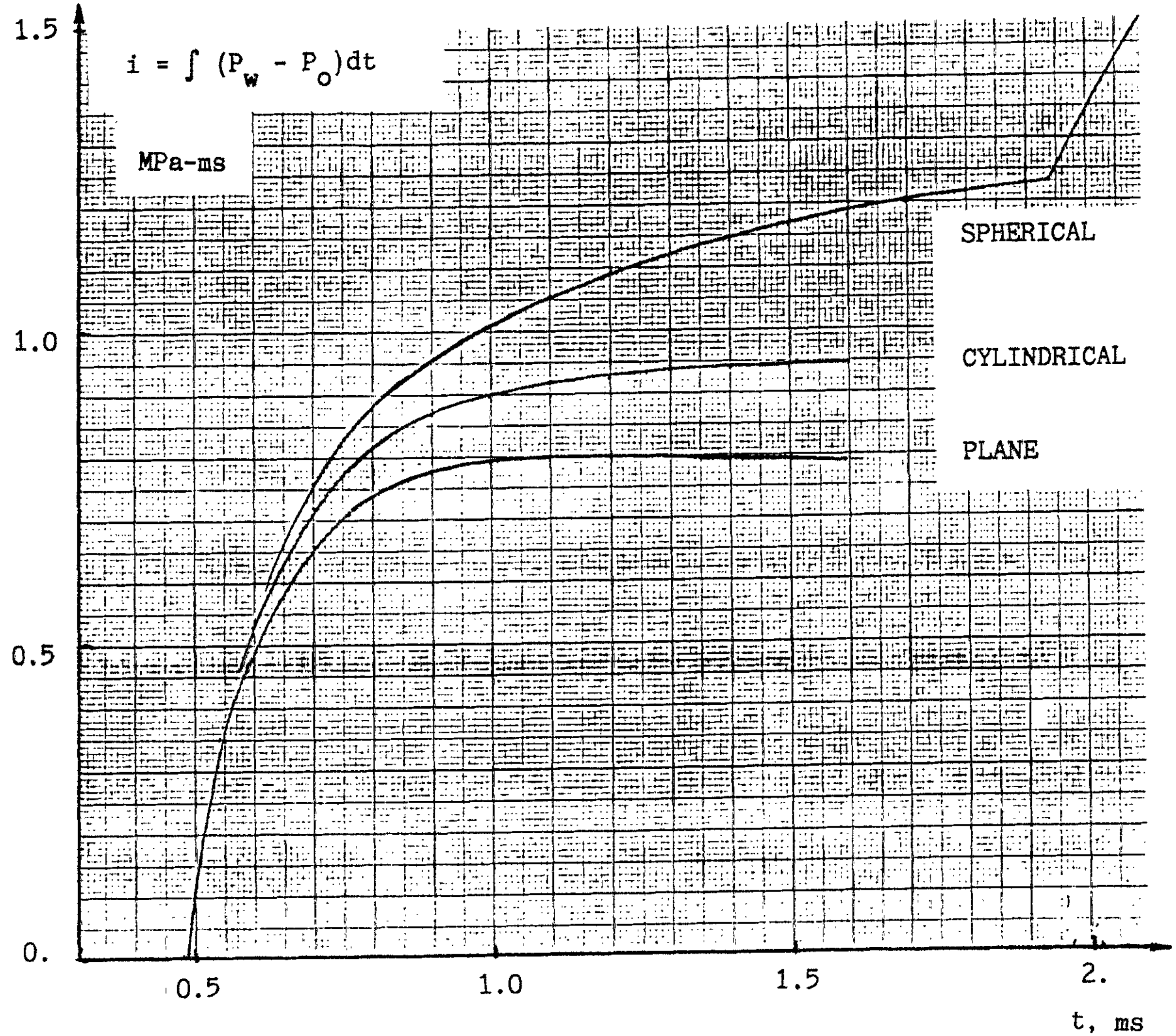

FIGURE 7: THE REFLECTED WAVE IMPULSE VS. TIME